In re Patent Application of:
COFFA ET AL.
Serial No. **09/653,390**
Filing Date: **September 1, 2000**

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REMARKS

Applicants would like to thank the Examiner for the thorough examination of the present application. Dependent Claims 30 and 39 are being cancelled to advance prosecution of the present case. The method claims that were previously renumbered as Claims 55-58 are also being cancelled as helpfully noted by the Examiner. The arguments supporting patentability of the claims are presented in detail below.

I. The Claims Are Definite

The Examiner rejected independent Claims 28 and 38 as being indefinite based upon the following positions: 1) information concerning the location and extent of the depletion layer (within the doped P/N junction) which includes the rare-earth material can not be derived from the specification; and 2) information concerning the depth of the rare-earth material buried within the doped P/N junction to define an acceleration space also can not be derived from the specification.

As the Examiner is aware, the depletion layer in a P/N junction is the area where free electrons have combined with holes to create an insulating barrier between the P and N regions. No carriers can cross the depletion layer until a bias voltage is applied to the P/N junction. When a positive bias voltage is applied, then the depletion layer becomes very thin so that carriers can easily cross the depletion layer. When the bias voltage is negative, then the depletion layer becomes wider and further acts as an insulator, making it more difficult for carriers to cross the depletion layer.

The depletion layer of a P/N junction is discussed throughout the Applicants' specification. In addition, the Coffa et al. article also discusses the depletion layer of a P/N junction. As recited in the claims, the depletion layer comprises at least one rare-earth material, such as erbium. The claims further recite that the rare-earth material is buried within the P/N junction at a depth sufficient for defining an acceleration space between a region of the P/N junction that generates carriers when the rare-earth material is being pumped. The acceleration space allows the carriers to be accelerated before reaching the rare-earth material.

Reference is directed to FIGS. 11-13 of the Applicants' specification. FIG. 11 illustrates the depletion layer of a P/N junction. FIG. 12 is a graph showing the doping concentration of erbium versus depth in the depletion layer. FIG. 13 is a graph showing the depth of the erbium in the depletion layer versus the electrical field strength needed to achieve the necessary excited states of erbium.

As discussed above, the depletion layer becomes wider when a negative bias voltage is applied to the P/N junction. The Applicants noted on page 11, line 31 through page 12, line 13 of the specification that carriers do not have enough energy to pump the erbium ions when the P/N junction is reversed biased. The Applicants overcome this problem by providing a sufficient acceleration space for the carriers before they enter the erbium doped region of the P/N junction (page 12, lines 27-28).

Referring to page 9, lines 22-26 of the Applicants' specification, a sufficient acceleration space is to be provided to allow the carriers to be accelerated before

reaching the erbium in the depletion layer. While a specific depth is not given, the Applicants respectfully submit that one skilled in the art can readily determine from the Applicants' specification that the depth will vary depending on the doping concentration of the erbium and the electrical field required to excite the erbium within the depletion layer, as best illustrated in FIGS. 12 and 13.

Accordingly, it is submitted that Claims 28 and 38 are definite.

II. The Claims Are Patentable

The Examiner rejected independent Claims 28 and 38 over the Benton et al. patent in view of the Franzo et al. article. Alternatively, the Examiner also rejected independent Claims 28 and 38 over the Benton et al. patent in view of the Coffa et al. article. Both of these rejections will be addressed below in this section.

The present invention, as recited in independent Claim 28, for example, is directed to a semiconductor laser device for electro-optic applications comprising a semiconductor substrate, and a doped P/N junction integrated with the semiconductor substrate. The doped P/N junction comprises a depletion layer and has a shape defining a waveguide. The depletion layer comprises at least one rare-earth material for providing a coherent light source. The semiconductor laser device further comprises a biasing device connected to the doped P/N junction for reverse biasing thereof.

All of the at least one rare-earth material remains in the depletion layer when the semiconductor laser device is

operating. Reverse biasing of the doped P/N junction produces coherent light by pumping the at least one rare-earth material at room temperature, and the at least one rare-earth material is buried within the doped P/N junction at a depth sufficient for defining an acceleration space between a region of the doped P/N junction that generates carriers when the at least one rare-earth material is being pumped. The acceleration space allows the carriers to be accelerated before reaching the at least one rare-earth material.

Referring now to the Benton et al. patent, FIG. 3 discloses an optical waveguide device that includes a silicon substrate **31**, an epitaxial silicon layer **32** on the substrate, an epitaxial silicon-germanium layer **33** on layer **32**, and an epitaxial silicon top cladding layer **34** on layer **33**. Layers **35**, **36** and **37** are metal contact layers that facilitate pumping of the device. The epitaxial silicon-germanium layer **33** has been doped with a rare-earth material, such as erbium. As correctly noted by the Examiner, the three-terminal optical waveguide device may also be configured as a two-terminal P/N structure. In addition, the Examiner correctly noted that Benton et al. fails to disclose that the optical waveguide device may be <u>reversed biased</u> to produce coherent light.

The Examiner cited the Franzo et al. and Coffa et al. articles as disclosing the reverse biasing of a P/N junction doped with a rare-earth material, such as erbium. In particular, the doped P/N junction disclosed in these articles is for light emitting diodes (LED). The Examiner has taken the position that it would have been obvious to reverse bias the optical waveguide device in Benton et al. to more efficiently produce coherent light.

It appears that the Examiner is using hindsight reconstruction to modify Benton et al. in view of the Franzo et al. and Coffa et al. articles in an attempt to produce the claimed invention. As the Examiner is aware, there must be some suggestion or motivation, either in Benton et al. or in the knowledge generally available to one of ordinary skill in the art, to modify Benton et al. to include reverse biasing of the erbium doped P/N junction at room temperature. However, the Applicants respectfully submit that the selective modification of Benton et al. in view of the Franzo et al. and Coffa et al. articles are not properly combinable.

The Applicants respectfully submit that operation of a doped P/N junction as <u>an LED which produces incoherent light</u> is notably different than operating a rare-earth material doped P/N junction as <u>a laser device which produces coherent light</u>. In fact, one of the inventors, Salvatore Coffa, is a joint author of one of the prior art references, and has recognized this problem in the present invention. In other words, the behavior of a rare-earth material in a doped P/N junction is very dependent on the semiconductor substrate, and the requirements to achieve laser emission are much more stringent than those to achieve an incoherent light emission as in an LED. In Benton et al., the optical waveguide device including a doped erbium layer is generally discussed - and only discloses in the last sentence of the detailed description (column 4, lines 66-68) that the optical waveguide device may be used as a laser or LED.

Moreover, even though Benton et al. discloses that the optical waveguide device may be configured to include a two-terminal P/N junction, there is no mention of doping the

depletion layer of the P/N junction so that all of the erbium remains in the depletion layer when the optical waveguide device is operating.

In the optical waveguide device of Benton et al., severe, non-radiated decay processes for erbium in silicon make it difficult to use erbium excitation by electron-hole pairs to fabricate an injection laser at room temperature. For example, in column 3, lines 44-50 of Benton et al., the disclosed laser was operated at 4.2K when data related thereto was collected. The only reference to operating the laser at room temperature is made in a generalized statement on line 50 that the collected data is expected to be substantially similar at room temperature.

Erbium excitation by hot carriers in a reverse biased P/N junction thus allows light emission to be achieved at room temperature, as disclosed in the Franzo et al. and Coffa et al. articles. However, as noted above, Franzo et al. and Coffa et al. refer to LEDs, i.e., devices in which incoherent light is generated. To obtain a coherent emission, i.e., a laser emission, an efficient electrical excitation has to be accompanied by the inversion of the optically active ions (so that a gain can be achieved) and by a reduction of the overall losses (so that a net gain can be achieved).

These requirements can not be achieved by simply using erbium doping in a reversed biased P/N junction. The present invention thus provides an approach to meet these requirements to achieve laser action by tailoring the doping of the rare-earth material and the device structure itself.

For example, when the laser device of the present invention is operated, all of the ions of the rare-earth

material are within the depletion layer of the P/N junction, as recited in independent Claims 28. This avoids rare-earth material ions form being left outside of this region, and hence, all of the rare-earth material ions can be pumped by hot carriers which are only present in the depletion layer. It should be noted that leaving some of the rare-earth material ions outside of the depletion layer would not produce any significant effect on an LED. On the other hand, this can kill laser action since the rare-earth material ions outside the depletion layer would be left in the ground state, and hence, they would absorb, rather than amplify, the coherent light.

In addition, some space needs to be left between the region of the maximum electrical field strength in the P/N junction (where the carriers are generated) and the depletion layer comprising the rare-earth material. This space allows proper acceleration of these carriers before they reach the ions of the rare-earth material. For example, 0.8 eV is needed to excite erbium ions from the ground state to the first excited state. Failing to meet this condition will produce a dark region in the center of the depletion layer, where erbium ions will not be pumped since the energy of the carriers will not be sufficient. Once again, these erbium ions would be left in the fundamental state and will absorb, rather than amplify, the coherent light.

The Applicants respectfully submit that there is no proper motivation or suggestion in the prior art to modify the optical waveguide device in Benton et al. so that it is reversed biased, and that all of the erbium in the P/N junction remains in the depletion layer thereof when the

optical waveguide device is operated as a laser at room temperature, as in the claimed invention. This is particularly so since the Franzo et al. and Coffa et al. articles are directed to LEDs, where it is not critical to the operation of an LED if some of the rare-earth materials are outside of the depletion layer. Therefore, the prior art references do not teach or suggest such a combination.

Accordingly, it is submitted that independent Claim 28 is patentable over Benton et al. in view of the Franzo et al. article and the Coffa et al. article. Independent Claim 38 is similar to independent Claim 28. It is also submitted that independent Claim 38 is patentable over the prior art references. In view of the patentability of independent Claims 28 and 38, it is submitted that their dependent claims which recite yet further distinguishing features of the invention are also patentable. These dependent claims need no further discussion herein.

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CONCLUSION

In view of the amendments to the claims and the arguments provided herein, it is submitted that all the claims are patentable. Accordingly, a Notice of Allowance is requested in due course. Should any minor informalities need to be addressed, the Examiner is encouraged to contact the undersigned attorney at the telephone number listed below.

Respectfully submitted,

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Justin Gore